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Reliability Concerns for GaAs-Based HBTs in DOD Space Systems

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Gallium-arsenide-based heterojunction bipolar transistor (HBT) circuits are known to be sensitive to current gain degradation associated with aspects of the semiconductor manufacturing process. This letter discusses the susceptibility of GaAs-based HBT circuits to a life-limiting failure mechanism and the impact of this failure mode on the use of these circuits in space system applications.

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This report is intended to provide summary information regarding the susceptibility of GaAs-based heterojunction bipolar transistor (HBT) circuits to a life-limiting failure mechanism in order to clarify why it is important to understand all applications of these circuits in space systems, including levels of circuit stress in operation and the selection, screening, and qualification history of these parts.

GaAs-based HBT circuits are found in various high-frequency applications in space systems. Depending on how these circuits are manufactured, they have been documented to be sensitive to current gain degradation associated with aspects of semiconductor processing. The failure mode involves steadily increasing base current over the part's operational lifetime, resulting in a continuous degradation of the bipolar current gain in these transistors. Several publications have discussed this failure mode [1-7]. The root cause of this failure mode is now believed to be the creation of minority-carrier recombination centers at the foot of the emitter mesa in the region of the extrinsic base. The reaction creating these recombination centers is driven by the hole current in the extrinsic base. The likelihood of this failure mode decreases with increasing thickness of the emitter ledge over the base layer, with thicker layers resulting in HBTs that are less susceptible to this failure mode [1]. Although many publications discuss this failure mode in reference to specific HBT structures, the failure mode may be more broadly applicable to any mesa-isolated GaAs-based HBT [3].

This failure mode has been observed to obey a relation in which the mean time to failure, MTTF, can be predicted by an equation containing a current power-law term and an Arrhenius term of the form

$$\mathrm{MTTF} = K\, J^{-n}\, e^{EA/kT},$$

where J is the mean emitter current density, n is an empirical factor, E_A is the activation energy, k is Boltzmann's constant, T is the operating temperature, and K is an empirically determined proportionality factor that may be lot-specific. The activation energy associated with this failure mode is less than 0.5 eV [1,3-7], which makes it difficult to accelerate with temperature. An important consequence of the very low E_A is that typical high-temperature accelerated life tests and screens may not be perceptive to this degradation mechanism. Additionally, it is possible that small amplitude changes in device performance during burn-in screens or life tests may be improperly dispositioned or overlooked if users are not aware of the potential presence of this low-activation-energy mechanism. The relatively strong current dependence makes this failure mode more easily detected using high-current test methods, and also makes these parts more susceptible to failure in high-current applications. Note also that degradation does not occur without applied bias [5], making the MTTF dependent on time of operation and duty cycle.

Because the root cause of this failure mode has not been well understood, an effective screening methodology for this mechanism has not been applied uniformly to all products manufactured over the past several years. As a result, the possibility exists that HBTs with poorly characterized reliability may have made their way into a number of satellite systems. In order to assess the reliability of existing DOD systems, it is therefore necessary to determine if and where GaAs-based HBT technology is used in DOD programs, and whether proper reliability screening procedures have been applied to those HBT circuits.

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